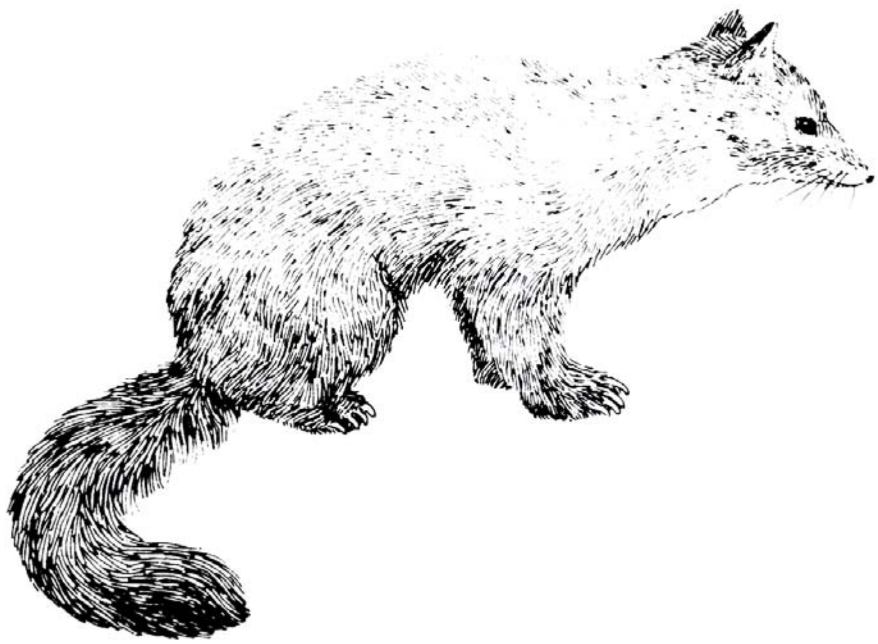
California Wildlife Habitat Relationships Program
California Department of Fish and Game

HABITAT SUITABILITY MODELS FOR USE WITH ARC/INFO: MARTEN



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by

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MARTEN (*Martes americana*)

HABITAT USE INFORMATION

General

The marten (*Martes americana*) inhabits late successional forest communities from Alaska south into California and the Rocky Mountains, through much of Canada, and into the northeastern U.S. (Hall 1981; Buskirk and Powell 1991). The species is most abundant in association with mature coniferous forests, but it also inhabits forests of mixed deciduous and coniferous species (Hagmeier 1956). Marten in Minnesota were observed or captured most often in conifer-dominated or mixed stands of coniferous and deciduous trees (Mech and Rogers 1977). Marten prefer mixed-conifer dominated stands in undisturbed forests in Maine (Soutiere 1979). In the western U.S., marten are associated mature and old-growth coniferous forests with dense canopies and high stem densities (Koehler et al. 1975; Meslow et al. 1981; Buskirk et al. 1989; Koehler et al. 1990; Buskirk and Powell 1994). In California, they are uncommon to common permanent residents of the North Coast, Klamath, Cascade, and Sierra Nevada ranges (Zeiner et al. 1990). Optimal habitats include various mixed-conifer forests with more than 40% canopy closure (Koehler and Hornocker 1977; Spencer et al. 1983; Martin 1987) and containing large amounts of basal area, downfall cover, living ground cover, and log density (Martin 1987). Important vegetation types in California include red fir (*Abies magnifica*), lodgepole pine (*Pinus contorta* var. *murrayana*), Jeffrey pine (*P. jeffreyi*), subalpine conifer, mixed-conifer, and eastside pine (Grinnell et al. 1937; Schempf and White 1977; Clark et al. 1987).

Food

Marten consume a wide variety of food items throughout the year (Martin 1994). Invertebrates, berries, and passerine birds were the most frequent food items recorded from spring through fall in a Montana study (Weckwerth and Hawley 1962). However, mammals were the most important food item on an annual basis with the highest utilization of mammalian prey occurring during the winter months. Microtine rodents, especially *Clethrionomys* spp. and *Microtus* spp., are major food items of martens during fall and winter (Cowan and Mackay 1950; Lensink et al. 1955; Weckwerth and Hawley 1962; Koehler and Hornocker 1977; Soutiere 1979; Buskirk and MacDonald 1984).

In California, small mammals and Douglas' squirrels (*Tamiasciurus douglasii*) are important items of the summer and winter diets, respectively, of marten (Grinnell et al. 1937). In the northern Sierra Nevada, mammals represented 41% (by relative volume) of the fall diet and 29%, 42%, and 31% of the winter, spring, and summer diets, respectively (Simon 1980). Birds constituted 12% of the fall diet, and 29%, 16%, and 25% of the winter, spring , and summer diets, respectively, while insects comprised 12% of the fall diet, 2% of the spring, and 7% of the summer diet. Squirrels were the most important marten food during the fall, spring, and summer followed by microtine rodents in the fall and spring (Simon 1980). In winter, microtine rodents occurred in the greatest volume in scat followed by squirrels and birds (Simon 1980). Zielinski et al. (1983) estimated that the mammalian component of the winter diet of marten in the northern Sierra

Nevada was 87.9%, while Martin (1987) estimated that the winter diet contained 69.1% mammalian material. The most common small mammalian prey items, measured by percent frequency of occurrence in scats, were montane voles (*Microtus montanus*) (10.6%), Douglas' squirrel (6.8%), and chipmunks *(Eutamias* spp.) (5.8%) (Martin 1987). A winter study of marten in the central Sierra Nevada found white-tailed hares (*Lepus americanus*) and voles (*Microtus* spp.) to be the dominate prey items with Douglas' squirrels a secondary item (Hargis and McCullough 1984).

Mech and Rogers (1977) reported that food availability is probably the most important factor affecting the distribution of marten. Fluctuations in small mammal densities in Montana were believed to directly affect the carrying capacity of the study area for marten (Weckwerth and Hawley 1962). In northcentral Ontario, responses of marten to a synchronous decline of prey species included reduced population density, enlarged home ranges, lower ovulation rates in 1 and 2 year old females, reduced production of young, dispersal of formerly resident adults, and cannibalism (Thompson and Colgan 1987). Clark and Campbell (1976) believed that limited access routes to get at prey below deep snow may be more restrictive on marten winter densities than actual rodent density.

Water

No water requirements for the marten were found in the literature.

Cover

Mesic stands of mature coniferous trees with a canopy closure of 40% or more supported the highest marten activity in Montana (Koehler and Hornocker 1977). These sites also supported the greatest number of rodents and contained the highest diversity of understory plant species. Subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*P. engelmannii*), and Douglas-fir (*Pseudotsuga menziesii*) stands were the most intensively used by marten during the winter months in Idaho (Marshall 1951). Stands of ponderosa pine (*P. ponderosa*) were used when adjacent to spruce-fir stands. Eighty percent of the marten observations in Colorado were in spruce-fir stands or in forest types that were at least partially comprised of spruce (Yeager and Remington 1956).

Forests with 40-60% canopy closure were preferred by martens in the Sierra Nevada (Sumner and Dixon 1953; Spencer et al. 1983; Martin 1987). Martens in the central Sierra Nevada preferred areas with overhead cover < 3 m (11 ft) above snow when traveling and pausing (Hargis and McCullough 1984). Many of the marten sightings in the Sierra Nevada occurred in true fir (*Abies* spp.) forests (Schempf and White 1977). However, in the northern Sierra Nevada, marten used lodgepole pine, mixed-conifer, and red fir forests more than expected based on their availability (Simon 1980). In the central Sierra Nevada, lodgepole pine forests, meadows, and streams were used in proportion to their availability (Hargis and McCullough 1984). Riparian lodgepole pine forests were preferred for hunting by marten in the lower Sagehen Creek Basin, adjacent mixed-conifer forests were preferred for resting, and mature red fir forests in the upper basin were preferred for both hunting and resting (Spencer et al. 1983).

Martens in Wyoming selected large (36-61 cm dbh [14-24 in]), rotten Engelmann spruce or subalpine fir snags as refuge sites (Clark and Campbell 1976). In California, snags used as resting sites by martens were almost exclusively large (mean dbh = 102 cm [41 in]) true fir (*Abies* spp.), while most live trees used as refuges were large (mean dbh = 62 cm [25 in]), deformed lodgepole pines (Spencer 1987). Snags, stumps, logs, and tree canopies comprised 77% of dens found in the northern Sierra Nevada (Martin 1987). Other commonly reported refuge sites include ground burrows, rock piles, and crevices (Mech and Rogers 1977), or downfall, stumps, brush or slash piles (Marshall 1951; Clark and Campbell 1976; Steventon and Major 1982), and red squirrel (*Tamiasciurus hudsonicus*) (Buskirk 1984) and Douglas' squirrel middens (Spencer 1981, 1987).

Downfall, in addition to providing refuge sites, allows marten access to below snow surface galleries of vegetation and fallen trees (Clark and Campbell 1976; Hargis and McCullough 1984; Bateman 1986; Snyder and Bissonette 1987; Corn and Raphael 1992). These "entry"' sites are critical to marten winter survival because they provide access to rodent prey active under deep snow. Such entry sites accounted for 93% of the recorded marten winter feeding sites in Wyoming. Ninety-seven percent of the marten winter resting sites located in Maine were beneath the snow surface within natural cavities formed around large decayed stumps (Steventon and Major 1982). These refuge sites were repeatedly used for several days at a time. In the northern Sierra Nevada, 91% of subnivean marten rest site observations were associated with logs, stumps, and snags (Spencer 1987). Cavities in decayed wood accounted for 51% of the observations, and holes beneath snow-covered logs or between piled logs represented an additional 41% of the observations (Spencer 1987). Martens in this study reused subnivean rest sites more frequently (42%) than they did non-subnivean sites (12%). Forty-nine percent of subnivean refuges in Wyoming were associated with coarse woody debris (CWD), including logs, stumps, and snags (Buskirk et al. 1989).

Marten "entry" sites in Wyoming had greater percent cover and total volume of CWD, greater numbers of log layers, and greater volume of undecayed and moderately decayed logs than did surrounding forest stands (Corn and Raphael 1992). Hagmeier (1956) found that, while martens ranged through a variety of vegetative types, most refuge sites were located within stands of coniferous trees. Summer refuge sites in Maine were in the crowns of conifer trees (Steventon and Major 1982). No refuge sites were located on the ground surface during this season. In the northern Sierra Nevada, stumps were used as dens approximately eight times more often in summer than winter, and snags and logs were used twice as often in winter than in summer (Martin 1987). Willow *(Salix* spp.) clumps were used nearly twice as often in summer as in winter, while tree canopies were used nearly three times as often in summer as in winter (Martin 1987).

Hawley and Newby (1957) believed that large openings serve as psychological barriers to marten, while Koehler and Hornocker (1977) believed that openings, which are avoided in the winter, may be used for foraging in the summer and fall seasons if adequate food and cover are present. Martens make little use of open clearings (Steventon and Major 1982; Spencer et al. 1983; Martin 1987), but may use riparian areas, stringer meadows (Spencer et al. 1983; Buskirk and Powell 1991) and forest edges (Simon 1980; Spencer et al. 1983; Martin 1987; Buskirk and Powell 1994). Martens traveled across meadows 50 m (165 ft) wide during winter in the central Sierra

Nevada but did not stop or hunt in them (Hargis and McCullough 1984). Meadows > 50 m (165 ft) were crossed under the cover of scattered trees. Martens occasionally crossed openings up to 165 m (540 ft) in width in Maine during the winter months (Soutiere 1979). Although windfall and slash protruding from the snow were investigated by martens, movements across such openings were more direct than movements within uncut forest stands. Martens in Colorado have been observed at distances ranging from 0.8-3.2 km (0.5-2.0 mi) from forest cover from May through November (Streeter and Braun 1968). However, in all instances but one, the species was observed in large boulder fields which provided a food source, pika (*Onchotona princeps*), and cover in the form of large boulders or rockslides.

Yeager (1950) believed that timber harvesting was the single most destructive factor contributing to the decimation of marten populations. Logging can destroy or degrade marten habitats for decades, resulting in precipitous declines in populations (Soutiere 1979; Strickland and Douglas 1987; Bissonette et al. 1989; Buskirk and Powell 1994). Marten in Wyoming did not utilize harvested timber stands for at least one year after cutting (Clark and Campbell 1976). Marten in Maine rarely used clearcut areas less than 15 years old but were found in selectively harvested stands (Soutiere 1979). Steventon and Major (1982) recorded strong avoidance of clearcut areas by marten during winter. Islands of uncut softwoods within and adjacent to clearcuts were heavily utilized for cover and foraging in summer and winter.

Reproduction

The reproductive requirements of the marten are assumed to be identical with cover requirements, as described above.

Interspersion and Composition

Marten populations are structured around male territories which are rigidly defended during the spring and summer months (Clark and Campbell 1976; Buskirk and Powell 1994). Home ranges of male martens are distinct, but female home ranges often overlap those of other females and males. Boundaries of marten home ranges often coincide with the edges of topographic or vegetative features, such as large, open meadows, burns, and streams (Hawley and Newby 1957).

Trapping and recapture studies of marten have produced estimates of minimum home ranges varying from 2-3 km^2 (0.8-1.2 mi^2) for males and 1 km^2 (0.4 mi^2) for females (Clark et al. 1987). Home range estimates based upon telemetry studies varied from 10-20 km^2 (4-8 mi^2) for males and 3-6 km^2 (1.2-2.4 mi^2) for females. The mean home range size for marten in Montana was 2.4 km^2 (0.9 mi^2) and 0.69 km^2 (0.27 mi^2) for males and females, respectively (Hawley and Newby 1957). Home range sizes in Wyoming were 2.4 km^2 (0.93 mi^2) for males and 0.88 km^2 (0.34 mi^2) for females (Clark and Campbell 1976). The average home range size in Minnesota was 15.6 km^2 (6.0 mi^2) for males and 4.3 km^2 (1.7 mi^2) for females (Mech and Rogers 1977). The average winter home range for male marten in Maine was 9.3 km^2 (3.6 mi^2) (Steventon and Major 1982).

Summer home range size was between 5.0-10.0 km^2 (1.9-3.9 mi^2). In the northern Sierra Nevada, the average home range size was 1.7 km^2 (0.7 mi^2) for males and 1 km^2 (0.4 mi^2) for females (Martin 1987).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area.

The California Wildlife Habitat-Relationships (CWHR) System (Airola 1988; Mayer and Laudenslayer; 1988, Zeiner et al. 1990) contains habitat ratings for each habitat type predicted to be occupied by marten in California.

Season.

This model is designed to predict the suitability of habitat for martens throughout the year. Model predictions, however, may be more accurate for breeding habitat.

Cover types.

This model can be used anywhere in California for which an ARC/INFO map of CWHR habitat types exists. The CWHR System contains suitability ratings for reproduction,

cover, and feeding for all habitats martens are predicted to occupy. These ratings can be used in conjunction with the ARC/INFO habitat map to model wildlife habitat suitability.

Minimum habitat area.

Minimum habitat area is defined as the minimum amount of contiguous habitat required before a species will occupy an area. Specific information on minimum areas required for martens was not found in the literature. This model assumes two home ranges is the minimum area required to support a marten population during the breeding season.

Verification level.

The spatial model presented here has not been verified in the field. The CWHR suitability values used are based on a combination of literature searches and expert opinion. We strongly encourage field testing of both the CWHR database and this spatial model.

Model Description

Overview.

This model uses CWHR habitat type as the main factor determining suitability of an area for this species.

A CWHR habitat type map must be constructed in ARC/INFO GRID format as a basis for the model. The GRID module of ARC/INFO was used because of its superior functionality for spatial modeling. Only crude spatial modeling is possible in the vector portion of the ARC/INFO program, and much of the modeling done here would have been impossible without the abilities of the GRID module. In addition to more sophisticated modeling, the GRID module's execution speed is very rapid, allowing a complex model to run in less than 30 minutes.

The following sections document the logic and assumptions used to interpret habitat suitability.

Cover component.

A CWHR habitat map must be constructed. The mapped data (coverage) must be in ARC/INFO GRID format. A grid is a GIS coverage composed of a matrix of information. When the grid coverage is created, the size of the grid cell should be determined based on the resolution of the habitat data and the home range size of the species with the smallest home range in the study. You must be able to map the home range of the smallest species with reasonable accuracy. However, if the cell size becomes too small, data processing time can increase considerably. We recommend a grid cell size of 30 m (98 ft). Each grid cell can be assigned attributes. The initial map must have an attribute identifying the CWHR habitat type of each grid cell. A CWHR suitability value is assigned to each grid cell in the coverage based on its habitat type. Each CWHR habitat is rated as high, medium, low, or unsuitable for each of three life requisites: reproduction; feeding; and cover. The geometric mean value of the three suitability values was used to determine the base value of each cell for this analysis.

Distance to water.

No water requirement was found for this species.

Species' distribution.

The study area must be manually compared to the range maps in the CWHR Species Notes (Zeiner et al. 1990) to ensure that it is within the species' range. All grid cells outside the species' range have a suitability of zero.

Spatial analysis.

Ideally, a spatial model of distribution should operate on coverages containing habitat element information of primary importance to a species. For example, in the case of woodpeckers, the size and density of snags as well as the vegetation type would be of great importance. For many small rodents, the amount and size of dead and down woody material would be important. Unfortunately, the large cost involved in collecting microhabitat (habitat element) information and keeping it current makes it likely that geographic information system (GIS) coverages showing such information will be unavailable for extensive areas into the foreseeable future.

The model described here makes use of readily available information such as CWHR habitat type, elevation, slope, aspect, roads, rivers, streams and lakes. The goal of the model is to eliminate areas that are unlikely to be utilized by the species and lessen the value of marginally suitable areas. It does not attempt to address all the microhabitat issues discussed above, nor does it account for other environmental factors such as toxins, competitors, or predators. If and when such information becomes available, this model could be modified to use it.

In conclusion, field surveys will likely discover that the species is not as widespread or abundant as predictions by this model suggest. The model predicts potentially available habitat. There are a variety of reasons why the habitat may not be utilized.

Definitions.

Home Range: the area regularly used for all life activities by an individual during the season(s) for which this model is applicable.

Dispersal Distance: the distance an individual will disperse to establish a new home range. In this model it is used to determine if Potential Colony Habitat will be utilized.

Day to Day Distance: the distance an individual is willing to travel on a daily or semi-daily basis to utilize a distant resource (Potential Day to Day Habitat). The distance used in the model is the home range radius. This is determined by calculating the radius of a circle with an area of one home range.

Core Habitat: a contiguous area of habitat of medium or high quality that has an area greater than two home ranges in size. This habitat is in continuous use by the species. The species is successful enough in this habitat to produce offspring that may disperse from this area to the Colony Habitat and Other Habitat.

Potential Colony Habitat: a contiguous area of habitat of medium or high quality that has an area between one and two home ranges in size. It is not necessarily used continuously by the species. The distance from a core area will affect how often Potential Colony Habitat is utilized.

Colony Habitat: Potential Colony Habitat that is within the dispersal distance of the species. These areas receive their full original value unless they are further than three home range radii from a core area. These distant areas receive a value of low since there is a low probability that they will be utilized regularly.

Potential Day to Day Habitat: an area of high or medium quality habitat less than one home range in size, or habitat of low quality of any size. This piece of habitat alone is too small or of inadequate quality to be Core Habitat.

Day to Day Habitat: Potential Day to Day Habitat that is close enough to Core or Colony Habitat can be utilized by individuals moving out from those areas on a day to day basis. The grid cell must be within Day to Day Distance of Core or Colony Habitat.

Other Habitat: Contiguous areas of low value habitat larger than two home ranges in size, including small areas of high and medium quality habitat that may be imbedded in them, are included as usable habitat by the species. Such areas may act as “sinks” because long-term reproduction may not match mortality.

The table below indicates the specific distances and areas assumed by this model.

Distance variables:	Meters	Feet
Dispersal Distance	4,816	15,800
Day to Day Distance/ Home Range radius	803	2,633

Area variables:	Hectares	M^2	Acres	Ft^2
Home Range	202.35	2,023,500	500	21,780,000
Core Habitat	404.70	4,047,000	1,000	43,160,000

Application of the Model

A copy of the ARC/INFO AML can be found in Appendix 1. The steps carried out by the macro are as follows:

1. **Determine Core Habitat**: this is done by first converting all medium quality habitat to high quality habitat and removing all low value habitat. Then contiguous areas of habitat are grouped into regions. The area of each of the regions is determined. Those large enough (two home ranges) are maintained in the Core Habitat coverage. If no Core Habitat is identified then the model will indicate no suitable habitat in the study area.

2. **Identify Potential Colony Habitat**: using the coverage from Step 1, determine which regions are one to two home ranges in size. These are Potential Colonies.

3. **Identify Potential Day Use Habitat**: using the coverage derived in Step 1, determine which areas qualify as Potential Day to Day Habitat.

4. **Calculate the Cost Grid**: Since it is presumed to be more difficult for animals to travel through unsuitable habitat than suitable habitat we use a cost grid to limit travel based on habitat suitability. The cost to travel is one for high or medium quality habitat. This means that to travel 1 m through this habitat costs 1 m of Dispersal Distance. The cost to travel through low quality habitat is two and unsuitable habitat costs four.

This means that to travel 1 m through unsuitable habitat costs the species 4 m of Dispersal Distance.

5. **Calculate the Cost Distance Grid**: A cost distance grid containing the minimum cost to travel from each grid cell to the closest Core Habitat is then calculated using the Cost Grid (Step 4) and the Core Habitat (Step 1).

6. **Identify Colony Habitat:** Based on the Cost Distance Grid (Step 5), only Potential Colony Habitat within the Dispersal Distance of the species to Core Habitat is retained. Colonies are close enough if **any** cell in the Colony is within the Dispersal Distance from Core Habitat. The suitability of any Colony located further than three home range radii from a Core Habitat is changed to low since it is unlikely it will be utilized regularly.

7. **Create the Core + Colony Grid**: combine the Core Habitat (Step 1) and the Colony Habitat (Step 6) and calculate the cost to travel from any cell to Core or Colony Habitat. This is used to determine which Potential Day to Day Habitat could be utilized.

8. **Identify Day to Day Habitat**: grid cells of Day to Day Habitat are only accessible to the species if they are within one half of a home range radius from the edge of the nearest Core or Colony Habitat. Add these areas to the Core + Colony Grid (Step 7).

9. **Add Other Habitat**: large areas (two home ranges in size) of low value habitat, possibly with small areas of high and medium habitat imbedded in them may be utilized, although marginally. Add these areas back into the Core + Colony + Day to Day Grid (Step 8), if any exist, to create the grid showing areas that will potentially be utilized by the species. Each grid cell contains a one if it is utilized and a zero if it is not.

10. **Restore Values**: all areas that have been retained as having positive habitat value receive their original geometric mean value from the original geometric value grid (see *Cover component* section) with the exception of distant colonies. Distant colonies (colonies more than three home range radii distant) have their value reduced to low because of the low likelihood of utilization.

Problems with the Approach

Cost.

The cost to travel across low suitability and unsuitable habitat is not known. It is likely that it is quite different for different species. This model incorporates a reasonable guess for the cost of movement. A small bird will cross unsuitable habitat much more easily than a small mammal. To some extent differences in vagility between species is accounted for by different estimates of dispersal distances.

Dispersal distance.

The distance animals are willing to disperse from their nest or den site is not well understood. We have used distances from studies of the species or similar species when possible, otherwise first approximations are used. More research is urgently needed on wildlife dispersal.

Day to day distance.

The distance animals are willing to travel on a day to day basis to use distant resources has not been quantified for most species. This issue is less of a concern than dispersal distance since the possible distances are much more limited, especially with small mammals, reptiles, and amphibians. Home range size is assumed to be correlated with this coefficient.

SOURCES OF OTHER MODELS

No other habitat models were found for the marten.

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APPENDIX 1: Marten Macro

```
/*          MARTEN

/* marmodel.aml - This macro creates an HSI coverage for the
/*               Marten.

/* Version:  Arc/Info 6.1 (Unix), GRID-based model.

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/* Revision: 2/10/95

/* ---------------------------------------------------------------

/* convert .ID to uppercase for info manipulations

&setvar .ID [translate %.ID%]

/* Start Grid

grid

/*

&type (1)  Initializing Constants...

/*   Homerange: the size of the species' homerange.

/*   DayPay: The amount the species is willing to pay traveling on
/*   a day-to-day basis.  Used to determine the area utilized on a
/*   day-to-day basis.

/*   DispersePay: Distance traveled when dispersing.  The amount
/*   the animal is willing to pay when dispersing from a core area.

/*   High:  The value in the WHR grid which indicates high quality habitat.

/*   Medium:  The value in the WHR grid which indicates medium quality habitat.

/*   Low:  The value in the WHR grid which indicates low quality habitat.

/*   None:  The value in the WHR grid which indicates habitat of no value.

/*   SpecCode: The WHR code for the species

/*   AcreCalc:  The number needed to convert square units
/*             (feet or meters) to acres.


&setvar SpecCode = M154

&if %.Measure% = Meters &then
  &do
    &setvar AcreCalc       = 4047
    &setvar Homerange      = 2023500
    &setvar DayPay         = 803
```

```
    &setvar DispersePay    = 4816
  &end
&else
  &if %.Measure% = Feet &then
    &do
      &setvar AcreCalc       = 43560
      &setvar Homerange      = 21780000
      &setvar DayPay         = 2633
      &setvar DispersePay    = 15800
    &end
  &else
    &do
      &type Measurement type incorrect, check spelling.
      &type Only Meters and Feet are correct.
      &goto &BADEND
    &end

&setvar High           = 3
&setvar Medium         = 2
&setvar Low            = 1
&setvar None           = 0

/*   The following global variables are declared in the menu:

/*  .WHRgrid (WHR grid name): the name of the grid containing all
/*   the WHR information.

/*  .Bound (Boundary grid name): the grid containing only the
/*   boundary of the coverage. All cells inside the boundary
/*   have a value of 1. All cells outside the boundary must
/*   have a value < 1.

/*  .ID (Identifier): a 1 to 4 character code used to identify
/*   the files produced by this program. You may prefer
/*   to use an abbreviation of the species' common name
/*   (e.g. use `fis1` for fisher).

/*  .SizeOfCell (Cell size): the size (width) of the cells
/*   used in the coverage grids. All grids used in the
/*   analysis must have the same cell size.

/*  .Measure:  the units the coverage is measured in (feet or meters).


&type (2)  Creating working grid of geometric means...

/*    Create a Geometric Means grid (Geom) for the species by
/*    copying these values from the WHR grid.

Geom = %.WHRgrid%.%SpecCode%_G

/*

&type (3)  Changing %Medium% value cells to %High% value for Merge grid...

/*    Create a grid (Merge) merging Medium and High
/*    value cells from the Geometric mean grid (Geom),
/*    while leaving the value of other cells (Low and None) unchanged.
/*    Merge by changing the value of all medium cells to High.

Merge = con(Geom == %Medium%,%High%,Geom)
```

```
/*

&type (4)  Converting Merge grid zones into a Region grid...

/*    Convert the zones of the merge grid (Merge) into
/*    unique regions (Region). These will be used later
/*    to create core, colony, and day-to-day areas.

Region = regiongroup(Merge,#,EIGHT)

/*

&type (5)  Calculating the area of Region grid zones...

/*    Calculate the area of the zones (ZoneArea) on the region
/*    grid (Region).

ZoneArea = zonalarea(Region)

/*

&type (6)  Creating a Core Area grid...

/*    Extract areas from the zonal area grid (ZoneArea)
/*    suitable for core areas (Core). Core areas are defined
/*    as the Medium+High zones in the merge grid (Merge)
/*    with an area of at least two home ranges (%Homerange%).
/*    Set their value = 1.

if (Merge == %High% and ZoneArea >= %Homerange% * 2)
  Core = 1
endif

&if not [exists Core -vat] &then
  &goto END

/*

&type (7)  Creating a Colony grid...

/*    Extract areas from the zonal area grid (zoneArea)
/*    possibly suitable for colonization (ColTemp).
/*    Colony areas are defined as Low or Medium+High zones
/*    in the Merge grid (Merge) with an area of between one
/*    and two home ranges (%Homerange%). Set their value = 1.

/*    Then set all nodata values in the grid to zero (Colony).

docell
  if (Merge == %High%)
    if (ZoneArea > %Homerange% and ZoneArea < %Homerange% * 2)
      ColTemp = 1
    endif
  endif
end

Colony = con(isnull(ColTemp),0,ColTemp)

/*

&type (8)  Creating a Day-to-Day Use grid...
```

```
/*    Create a grid based on the values in the zonal
/*    area grid (ZoneArea) and merge grid (Merge)
/*    suitable for day-to-day use (DayToDay). Day-to-day use
/*    areas are defined as Low if the area is less than two
/*    homeranges in size or Medium+High zones in the
/*    merge grid (Merge) with an area of less than one home
/*    range (%Homerange%). Set their value = 1.

if ((Merge > %Low% and ZoneArea <= %Homerange%) or ~
    (Merge == %Low% and ZoneArea < %Homerange% * 2))
  DayToDay = 1
else
  DayToDay = 0
endif

/*

&type (9)  Creating a Cost Grid based on habitat value...

/*     Using the merge grid (Merge), create a cost grid (Cost)
/*     based on the habitat-value. Cost represents the relative
/*     resistance a species has to moving across different quality
/*     habitat:   Habitat-value   Cost
/*                None            4
/*                Low             2
/*                Medium+High     1

if (Merge == %None%)
   Cost = 4
else if (Merge == %Low%)
   Cost = 2
else if (merge == %High%)
  Cost = 1
endif

/*

&type (10) Calculating cost to travel from Core Areas...

/*     Calculate the cost to travel the distance (CostDist)
/*     from the nearest core area source (Core) using the cost
/*     grid (Cost).
/*

CostDist = CostDistance(Core,Cost)

/*

&type (11) Calculating which Colony areas are Cost Effective...

/*     If Colony Areas exist...
/*     Find the areas in the Colony grid (Colony) that could
/*     be colonized from the core areas:

/*     Assign costs to all cells in the Colony areas (Colony)
/*     from the Cost grid (CostDist). Zero surrounding NODATA areas.

/*     Make each colony a separate zone (ZoneReg) using
/*     the regiongroup command.
```

```
/*    Use zonalmin to find the minimum cost to arrive at each
/*    colony (ZoneMin).

/*    Set all NODATA cells to zero in ZoneMin to produce
/*    ColZer1.

/*    To find out which of the potential colonies can be utilized,
/*    determine which have a cost that is equal to or less than
/*    DispersePay. If the cost to get to a colony is less than
/*    or equal to DispersePay, keep it in grid Col.

/*    Fill the null value areas in Col with zeros to create ColZer2


&if not [exists ColTemp -vat] &then
  &goto SkipColony

ColDist = con(Colony > 0,CostDist,0)
ZoneReg = regiongroup(Colony,#,EIGHT)
ZoneMin = zonalmin(ZoneReg,ColDist)
ColZer1 = con(isnull(ZoneMin),0,ZoneMin)

if (ColZer1 <= %DispersePay% and ColZer1 > 0)
  Col = Colony
else
  Col = Core
endif

ColZer2 = con(isnull(Col),0,Col)

/*

&type (12)  Creating Core + Colony grid...

/*    If colonies exist....
/*    Create a grid (ColCore) that combines the core
/*    (Core) and colony (Colony) grids.
/*    This grid will be used to analyze day-to-day use.


if (Colony == 1)
  ColCore = 1
else
  ColCore = Core
endif

&label SkipColony


&type (13)  Calculate cost to travel from Core and Colony Areas...

/*   If colonies exist...
/*   Calculate the cost to travel the distance (CostDis2)
/*   from the nearest core or colony area source (ColCore).
/*   Otherwise just copy the CostDist grid to use for Day-to-Day
/*   analysis.

&if not [exists ColTemp -vat] &then
  CostDis2 = CostDist
&else CostDis2 = CostDistance(ColCore,Cost)
```

```
/*

&type (14) Calculating which Day-to-Day areas are Cost Effective...

/*    This step adds the utilized Day-to-Day cells to the
/*    Core + Colony Area grid (ColZer2) to produce the
/*    Day1 grid.

/*    Use the Core + Colony Cost grid (CostDis2)to find out
/*    what can actually be used day-to-day (any cell with
/*    a cost of DayPay or less).

/*    Retain any cell in the Day-to-Day grid (DayToDay) with
/*    a cost less than or equal to DayPay and greater than zero.

/*    If the Distance-Cost grid (CostDis2) = 0,
/*    it is part of the Core or Colony Area and
/*    should gets its value from Core + Colony Area
/*    grid (ColZer2).

&if [exists ColTemp -vat] &then
  &do
    if (CostDis2 <= %DayPay% and CostDis2 > 0)
      Day1 = DayToDay
    else
      Day1 = ColZer2
    endif
  &end
&else
  &do
    if (CostDis2 <= %DayPay% and CostDis2 > 0)
      Day1 = DayToDay
    else
      Day1 = Core
    endif
  &end

/*

&type (15)  Finding Other Areas That May Be Utilized....

/*    This step picks up any large low value areas and any small
/*    medium or high value polygons that are imbeded
/*    in them.

/*    First find any areas that are not currently in the included
/*    set (Day1Z) but are in the original geometric mean coverage (geom)
/*    set Other to 1 where Day1Z = 0.

/*    if Other is all nodata, create the All coverage from
/*    the Day1Z coverage.

/*    Split all other areas into separate regions (OthReg)

/*    Calculate the area of the regions (OthArea).

/*    Keep any region in OthArea with an area > 2 homeranges (Util).

/*    Change any null values in Util to zeros (OthZero).

/*    Add these areas to the Day1 coverage to create All
```

```
Day1Z = con(isnull(Day1),0,Day1)

if ((Day1Z < 1) and (Geom > 0))
  Other = 1
endif

&if not [exists Other -vat] &then
  All = Day1Z
&else
  &do
    OthReg = regiongroup(other,#,EIGHT)

    OthArea  = zonalarea(OthReg)

    if (OthArea >= %Homerange% * 2)
      Util = 1
    else
      Util = 0
    endif

    OthZero = con(isnull(Util),0,Util)

    if (OthZero == 1)
      All = OthZero
    else
      All = Day1Z
    endif
  &end

/*

&type (16) Creating a Value grid...

/*     For any cell in All that has a value of 1, store the suitability
/*     value from the Geometric mean grid (Geom) to the Value grid.

/*     Other cells inside the boundary (%.Bound%) get a value of 0.

/*

if (All == 1)
  Value = Geom
else if (%.Bound% == 1)
  Value = 0
endif

/*

&type (17)  Creating an HSI grid...

/*     if Colonies exist....
/*     For any cell that was part of a colony that is further than
/*     3 times the HR radius (DayPay) away from a core area, set the suitability
/*     to Low.  Distant colonies lose value because of their small size.
/*     This step produces grid Collow.

/*     Set all NODATA values in Collow to zero in ColZer3.

/*     Find any day-to-day use areas (DayToDay) that are being
/*     utilized (ColZer3).  If they are further than four homeranges
/*     from a core area (CostDist), they are utilized from a distant
```

```
/*     colony and their value will be decreased to Low in Day2.


/*     Then change nulls to zero in ValZero

/*     Keep all data within the boundary; call this final grid HSI.

&if [exists ColTemp -vat] &then
  &do
    if (ColZer1 >= %DayPay% * 3)
      Collow = %Low%
    else
      Collow = Value
    endif

    ColZer3 = con(isnull(Collow),0,Collow)

    if ((CostDist > %DayPay% * 4) and (ColZer3 > 0) and ~
        (DayToDay == 1))
      Day2 = 1
    else
      Day2 = ColZer3
    endif
  &end
&else
    Day2 = Value

valzero = con(isnull(Day2),0,Day2)

if (%.Bound% == 1)
  %.ID%hsi = valzero
endif

/*

&type (18)  Quiting from GRID and adding the acres field.....

/*     Quit from GRID (Q), then run additem to add an acre item to
/*     the HSI grid vat file (%ID%HSI.vat). Reindex on value when done.

Q
additem %.ID%hsi.vat %.ID%hsi.vat acres 10 10 i
indexitem %.ID%hsi.vat value

/*

&type (19)  Calculating acres.....

/*    Use INFO to calculate the acreage field: Multiply the number
/*    of cells by the cell size squared and divide by the number of
/*    square meters per acre (4047). Reindex on value when done.

&data arc info
arc
select %.ID%hsi.VAT
CALC ACRES = ( COUNT * %.SizeOfCell% * %.SizeOfCell% ) / %AcreCalc%
Q STOP

&END

indexitem %.ID%hsi.vat value
```

```
/*

&type  (20) Killing all intermediate coverages before ending macro...

/* &goto OKEND

grid

kill Geom
kill Merge
kill Region
kill ZoneArea
kill Core
kill ColTemp
kill Colony
kill DayToDay
kill Cost
kill CostDist
kill ColDist
kill ZoneReg
kill ZoneMin
kill ColZer1
kill Col
kill ColZer2
kill ColCore
kill CostDis2
kill Day1
kill Day1Z
kill Other
kill OthReg
kill OthArea
kill Util
kill OthZero
kill All
kill Value
kill Collow
kill ColZer3
kill Day2
kill valzero

q

&goto OKEND

&label END
&type **
&type **
&type NO CORE AREAS EXIST, EXITING MACRO
&type **
&type **

kill Core
kill Region
kill ZoneArea
kill Merge
kill Geom

quit

&label OKEND
&label BADEND
```

&type -–------------ All done! ----–-----------

&return